Guideline for Reclamation of Drainage Basins and Channels Disturbed by Surface Coal Mining

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I. Introduction

Drainage basins and channels are a dynamic part of any landscape, and have significant influences on ecosystems and hydrologic systems. The configuration of natural drainages and channels is the result of many years of variable precipitation and runoff, modified or influenced by other factors (changes in bedrock, geologic structure, faults, etc.). Operators and regulators working in the context of the Montana Strip and Underground Mine Reclamation Act (MSUMRA), however, cannot wait for the full succession of natural processes to take their course on reclaimed lands. We need to regrade, resoil and revegetate the landscape expeditiously. We need to anticipate natural development and by careful planning and construction, limit the scale of erosional adjustments needed to reach an appropriate level of channel stability, meet other performance requirements set forth in MSUMRA, and achieve "bond release."

For purposes of this guideline, “drainage channels” are generally defined as landscape features that are anticipated or observed to be created by overland flow of ephemeral, intermittent or perennial waters that have become concentrated into more or less discernible flow paths. For specific definitions of many of the terms used in this guideline, including "channel", please refer to **APPENDIX A, "Drainage Reclamation - Related Definitions.**" Drainage channel or channel reaches may be in upland or lowland areas, may be vegetated or not, and may exhibit different degrees of stability.

Drastically disturbed drainage basins and channels must be reclaimed to approximate pre-mining drainage morphology and hydrologic processes, and with a drainage pattern that blends into and complements the surrounding terrain. They approximate pre-mining channel and floodplain characteristics, and meet other reclamation goals. The average channel gradient must be maintained with a concave longitudinal profile. Such reclamation must minimize changes to the pre-disturbance hydrologic balance, reestablish essential hydrological and ecological functions, and meet post-mining land use requirements. Reclaimed drainages must achieve a degree of relative stability complementary to post-mining drainage basin conditions and land uses, without excessive erosion or soil loss, before release of reclamation liabilities. Entire drainage systems may need to be reclaimed, or only those portions of the disturbed system that interface with undisturbed upstream and/or downstream and tributary drainage systems.

The challenges of drainage reclamation (especially during the initial years after re-grading, soil laydown, seeding and planting) have led to drainage reclamation design and construction requirements and standards as noted in Administrative Rules of Montana (ARM) 17.24.634, and in related rules, notably ARM 17.24.314, 501, 631, 711 and 751. Specific drainage channel designs must be submitted for Departmental (Montana Department of Environmental Quality) review and approval prior to construction of drainage channels denoted on post-mining topographic maps, unless an exemption has been approved by the Department [ARM 17.24.634 (2)]. The Department will work with permittees to delineate the drainage channels and/or reaches that require review and approval of designs per ARM 17.24.634 and related rules.

These drainage reclamation requirements have also led to a number of questions:

(1) What are the criteria for general drainage basin reclamation plans?

(2) When is a drainage channel design required?

(3) What level of channel design is required? What are the data requirements?

(4) What channel design methods and approaches should be employed?

(5) What are the construction and maintenance requirements?

Sections III, IV, and V of this guideline are intended to help answer these and related questions and to note information and criteria used by the Department in evaluating proposed plans for reclaimed drainages and channels. The guideline is particularly relevant to reconstruction of small to mid-sized upland drainages and channels (primarily moderate-to-higher-gradient ephemeral or intermittent channels) and mid-sized to larger lowland drainages and channels (primarily moderate-to-low-gradient ephemeral and intermittent channels).

II. <u>Maps, Data, and Other Resources</u>

The following fundamental resources are, for the most part, commonly submitted with and approved as part of a mine permit application. When available, they will be used by permittees and the Department in developing and evaluating drainage basin, and drainage channel designs:

- Aerial photos of the pre-mine area (with scale and coordinates provided)
- Pre-mine topographic ("Original Contour") maps
- Pre-mine vegetation, land use and wildlife maps, and related data
- Post-mine topographic ("PMT") maps (proposed and approved)
- Revegetation, post-mine soils, land use and wildlife maps and related data
- Longitudinal profiles with representative cross-section and plan view drawings or surveys of pre-mine and proposed post-mine drainage channels

Map, aerial photo, and profile scales must be adequate to show relevant features (e.g., 1 in. = 400 ft. with 5 or 10 ft. contour intervals minimum, with greater detail as needed)[1]. Long profile, cross-section and plan view drawings of channels should include relevant pre-mining, existing re-grade, or post-mining data in the same drawing to

[1] All detail on maps must be clearly legible and meet other applicable criteria of ARM 17.24.305, 313, etc.

simplify comparisons. Digital map, photo, and survey data should be submitted where possible, especially for larger drainages.

Landscape photographs and/or video imagery of representative pre-mine drainage basins and channels (e.g., landscape morphology, vegetation, ecological perspectives, and land uses) would also be a useful reference in design, construction, and evaluation of reclaimed drainages. Photo locations should be noted on relevant maps or aerial photos[2].

III. General Drainage Basin Reclamation
"What are the criteria for general drainage basin reclamation plans?"

Evaluations of drainage *basin* designs will be conducted primarily as part of DEQ's 'overall' reviews of mine permit applications or permit revisions. Please refer to ARM 17.24.301 through 17.24.327, 501, 631, and other relevant Departmental guidelines (e.g. Vegetation, Wildlife, Soils, Approximate Original Contour and Post Mine Topography, (AOC and PMT) guidelines, and other relevant Hydrology guidelines) for specific information about considerations pertinent to drainage basin reclamation plans, evaluation, etc.

Drainage basins, channels, and main tributaries must be shown on both pre-mine and post-mine topographic maps. Drainage reclamation requires that operators consider individual channels and tributaries in relation to their respective drainage basins. The operator must also provide descriptive summaries of relevant drainage basin, channel and tributary geomorphology and hydrologic characteristics, including: drainage/subdrainage areas, drainage density; valley gradient and length; floodplain width; 100-year, 24-hour discharge and velocity estimates, and properties of drainage bottom materials (e.g., bed and bank materials, surficial and near-surface substrates) and vegetation[2].

A description of the procedure and sequence for soiling, seeding and planting of drainage basins, floodplains, and channels where appropriate must be provided. This information aids in evaluating drainage reclamation plans relative to post-mine hydrologic and land use goals. For example, an operator may propose to soil, seed, and plant the side-slope areas of a drainage a year or two prior to soiling and planting the more dynamic channel and floodplain areas of the drainage bottom. It may also be desirable to distribute less soil in the upper reaches of the drainage with deeper soil in the lower reaches to approximate pre-mine soil distribution and to provide for related vegetative composition and production. Different soil textures and/or organic matter content may also be needed to approximate pre-mine soil, hydrologic and vegetation characteristics.

This information needs to be submitted with a mine permit application or permit revision. An operator may choose to defer submitting of soiling, seeding, and planting information specific to channel reclamation until submittal of designs specific to ARM 17.24.634(2).

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[2] See ARM 17.24.312-14, 320, 323-5, 501, 505, 515, 519-20, 631, 633-39, 640-44, 702-11, 751, 762, 801-26 for examples.

IV. Drainage Channel Designs

"When is a drainage channel design required?"

To keep the designation of drainage channels (and networks) relatively simple and work within a well-established geomorphologic framework, the stream-order system offers a logical method for categorizing channels for reclamation evaluation (see discussion of Strahler's method in Leopold, 1994). The uppermost channels, beginning somewhere near the drainage divide, are first-order channels (which have no tributaries). They include all definite draws and swales including those not indicated on maps by "bluelines" or other lines or symbols (Leopold, 1994) on U.S.G.S. 7-1/2 minute or other topographic maps. Where two first-order channels come together, they form a second-order channel. Where two second-order channels come together, they form a third-order and so on. This is relatively simple and consistent with other geomorphic measures used in comparing pre-mine and post-mine topography (e.g., channel length, drainage density, and channel slope)[3].

The relationships among stream order, drainage density, AOC/PMT and overall reclamation suggest that a good starting point for some level of channel design begins with second-order (and higher) channels. There can be some difficulties determining where the smallest first-order tributaries begin, but less difficulty where they join, (i.e., where second-order tributaries begin). Note that there may be cases where even small first-order tributaries, especially in steeper terrain, require some level of design (e.g., concave longitudinal profile and appropriate cross section) and extra care in construction. As discussed in ARM 17.24.634(2), the department may also exempt all or portions of a drainage channel (e.g., second-order or higher) from design requirements beyond those designs denoted in the overall basin submittals (Section III). It is important to note that the Department interprets the design requirement somewhat openly, to include different levels of detail or information as appropriate.

The operator is encouraged to designate and label on relevant PMT maps the location and extent of channels, reaches of channels, and/or categorized channels (e.g., categorized within a specific set of generic channel design criteria) that correlate to specific design criteria. Designations such as second-order, third-order, etc. may be useful for this purpose, although various means of designating, labeling and/or categorizing drainage channels may be acceptable. When an operator chooses to categorize channels and propose generic designs, details of category descriptions and related designs must be submitted for Department review and approval. Please refer to the section below entitled *"What level of channel design is required? What are the data requirements?"* for discussion about generic designs.

Deciding which drainage channels require designs, and whether the designs are sufficiently detailed and adequate for the intended purposes, will to some degree be case-

[3] Note that because we use topographic maps to represent more detailed ground features, it's important to maintain consistent scale, contour interval and details for a fair comparison of pre-mine and post-mine drainage networks, and drainage basin and channel geomorphology.

and/or category-specific. In deciding which reclaimed drainages need some level of design beyond the overall AOC/PMT requirement, the Department has considered a variety of known drainage characteristics. These include drainage area, channel slope, basin topography, geology and soils, and land use. An evaluation of channel and/or floodplain dimensions of pre-mine channels is also a part of the decision process. The last includes estimates of bankfull flow, channel width and depth, and floodplain width. Practical considerations of field construction/reclamation capabilities, and natural channel development potential, are also considered. One of the most basic factors influencing channel configuration is drainage area. However, use of a minimum drainage area threshold alone for determining a requirement for (or exemption from) designs would not consistently reflect the often significant differences in such things as topographic complexity, geology, drainage density and pattern between similar-sized drainages (e.g., steeper upland and flatter lowland terrain, southern and northern aspects, etc.).

"What level of channel design is required? What are the data requirements?"

Each "non-exempted" drainage channel (or portion of channel) will require some level of reclamation design beyond the basin design requirements noted in Section III. The simplest channel designs may consist of a commitment to construct a concave longitudinal profile, a particular alignment, slope, landscape position, and a specified soiling and revegetation plan. Other channels may require more detailed construction specifications. In some cases, channel-specific design criteria may be necessary. In many other cases, similar channel types may be grouped/categorized according to a relatively simple set of design and construction characteristics (e.g., see Rosgen, 1994).

The operator must provide longitudinal profiles, representative cross-sections, and plan view drawings for all "non-exempted" drainage channels and/or categorized channels to be reclaimed. The information should be included for each distinct channel reach, or for each category of channels or reaches with similar slope, substrates, and drainage area (typically reaches above, between and below tributary junctions). Any related pre-mining drainage survey data and/or descriptive information must also be provided for evaluating proposed drainage channel reclamation designs. Dimensions and related details of reconstructed channels must correlate with relevant channel, floodplain, adjacent valley sideslope or terrace characteristics, and will be evaluated in relation to specific hydrological, ecological and/or post-mine land use goals and criteria.

More detail may be required for more complex drainages or reaches (e.g., channels with steeper slopes or problem substrates; channels which may be prone to excessive erosion during the first year or two after construction before the channel is fully revegetated and channels intended to meet some particular reclamation goals and standards). For these, the operator should provide descriptions and estimates (mean and range) of drainage basin, floodplain and channel dimensions, and hydrologic characteristics relevant to construction (and/or natural development) of channels within a reclaimed drainage basin. This information should include but is not limited to: size of drainage/subdrainage areas; drainage bottom and/or floodplain width; channel width, depth, width/depth ratio, slope, and meander wavelength; bankfull and 100-yr., 24-hour discharge and velocity estimates; properties of drainage bottom materials (soil or other appropriate substrate) and vegetative cover. This information will be used along with other relevant information submitted as noted in the criteria of Section III, General Drainage Basin Criteria in evaluating channel designs..

As discussed above, the department encourages development of categorized channel reclamation plans for similar drainage types. Channel design categories may include a *range* in dimensions of: drainage bottom and/or floodplain width; channel width, depth, width/depth ratio, and meander wavelength; bankfull and 100-year, 24-hour discharge and velocity estimates for specified groups of drainage channels and basins. Final construction based on any design plans will likely include some field adjustments for specific drainage basin characteristics, properties of drainage bottom materials (soil or other appropriate substrate) and approved revegetation and landuse plans. Such adjustments should be evaluated and implemented in consultation with the Department.

"What channel design methods and approaches should be employed?"

Where post-mine drainage basin topography will approximate pre-mine topography, the relevant pre-mine topography, long profile and cross section data should be used to guide reclamation of drainage basin features such as channels. For example, appropriate pre-mine valley, terrace, floodplain, and channel features should be evaluated to design similar post mine features.

Other methods of designing reclaimed drainage channels, etc. are available and may need to be employed (e.g., when pre-mine data is unavailable or inappropriate, etc.). Appendix B (Figures 1, 2 and 3 and Table 1) suggests some starting points for consideration in deriving and/or categorizing reclaimed drainage channel design information based on some eastern Montana regional data. For example, Figures 1 and 2 (Bankfull Channel Dimensions vs. Drainage Area for Southeast & East-Central Montana USGS sites), shows the relationship between bankfull width, mean depth and drainage area for channels in Southeast and East-Central Montana (MT data from Parrett, et. al., 1987; Omang, 1992; and unpublished data from Charles Parrett, personal communication, 5/2001; Upper Green River, WY and Upper Salmon River, ID data from Dunne & Leopold, 1978; and Emmett, 1975). These data and the USGS peakflow equations associated with them provide regionally based methods for estimating bankfull flow (Figure 3), channel width and mean depth.

Additional channel and floodplain design characteristics can be estimated from relationships established in other hydrologic or geomorphic studies. For example, floodplain width can be estimated relative to bankfull channel width based on channel slope and type (e.g., generally narrower with steeper channels, and wider with lower gradient channels, see Table 1). Assuming the zone within which channel meandering occurs (meander belt) is roughly similar to floodplain width, the ratio of meander beltwidth to bankful channel width ("meander width ratio") shows the relationship between bankfull channel and floodplain width. For example, an average estimate of floodplain width for a moderately steep channel of 2-4% slope with a 3 foot wide bankfull width would be approximately 12 feet [(e.g., 3 ft x 3.7; see Table 1. Note also that because channel meander length (wavelength) for a wide variety of channels ranges from about 10 to 14 times bankfull channel width (Leopold, 1994), point bar spacing within the floodplain should generally be 5 to 7 times bankfull channel width (two alternate point bars in a full meander wavelength).]

Appendix B, Table 2 (Generic Channel Design Parameters Based on Bankfull Flow) suggests another example of some "starting points" based on a model. This Table provides estimates of channel parameters for channels with slopes ranging from 2 to 5 percent and with 4H:1V sideslopes. The values were derived from the SEDCAD 3.0 modeling program with cfs input correlated to width/depth and entrenchment ratios. Generic designs outside the range of 2 to 5% slopes can be generated in the same manner. The cfs values can be obtained through use of modeling, including the Omang (1992) regression equations, or other acceptable means.

Other methods of deriving and/or categorizing channel design information are of course conceivable (e.g., utilization of pre and post-mining drainage basin and channel characteristics[4], pre-mine channel data re: depth, width, etc.) and may be presented to the department for consideration. Any methodology used to derive channel designs should be re-evaluated and improved by incorporating information gleaned from observations made and data gathered after channels have been constructed and subjected to in-situ hydrologic and other environmental influences. The degree of success or failure of channel designs will be reflected by degree of achievement of specific channel-influenced land uses (establishment of targeted plant species or groupings, habitats, etc.) and hydrologic functions.

V. Construction, Monitoring and Maintenance
"What are the construction and maintenance requirements?"

As noted in Section IV, operators will be required to estimate a range of acceptable bankfull discharge channel widths, floodplain widths, width/depth ratios, and meander wavelengths for many drainage channels or categories of channels. The approved channel and floodplain features may be built with a variety of construction or farming implements (graders, small dozers, tractors, etc.), or channels may be allowed to develop naturally over a reasonable time within constructed floodplains or upland swales, within appropriate geomorphic limits and within approved ranges of acceptability.

Some as-built deviations from approved channel design may be acceptable and even desirable for achieving post-mine land use goals and standards, while others may not. For example, where an as-built longitudinal channel profile may vary from true concavity, the department will evaluate whether the variation indicates a potential channel stability problem or would interfere with or enhance post-mining utility of the drainage.

Reclaimed drainages must approximate widely variable characteristics of pre-mining drainages. Operators are, therefore, encouraged to incorporate some

[4] See Leopold, 1994; Omang, 1992; Parrett et al, 1987 and Rosgen, 1994, 1996.

comparatively small-scale variability, as appropriate, in reclaimed drainages (e.g., sideslope features such as small depressions or hillocks) and/or channels (e.g., vegetation niches).

In all cases, operators should plan for and monitor any natural channel and floodplain development that may occur. Such development may in some cases be capitalized on for meeting approved land use goals; in some other case, maintenance or reconstruction may be required. Smaller headcuts, incised reaches, or other irregularities in constructed and developing channels may result in only localized erosion and deposition, similar to pre-mine, and may enhance the likelihood of successful establishment of approved revegetation and/or land use. Larger headcuts and irregularities that prevent successful establishment of approved revegetation and/or landuse need to be corrected.

Maintenance or regrading work may be necessary where such things as channel stability problems, irretrievable soil loss, offsite impacts, or obstacles to post-mine land use occur or are likely to occur. Such maintenance or regrading determinations may result from field inspection and/or review of as-built surveys. This work might require the use of construction or farming implements. In many cases, various "normal husbandry practices" (e.g., installation of hay/straw bales, point bars, concentrated shrub planting, etc.) may be used to develop or maintain an appropriate level of channel and floodplain stability within and adjacent to the reclaimed channels. This work is most likely to be needed during the first few years after the drainage has been graded and/or planted. Operators are encouraged to submit or reference a description of the construction phases and techniques anticipated for drainage channel and floodplain reconstruction, triggers for evaluating or initiating potential maintenance, and proposed maintenance methods.

Periodic monitoring of reconstructed channels will be conducted by the Department and should also be conducted by operators to evaluate erosion developments and maintenance needs, and to facilitate accomplishment of performance requirements set forth in MSUMRA and bond release.

Drainage and channel repairs or maintenance needs will be determined in the context of ARM 17.24.634, 638, 702(5)(6), 711-723, 751, 762, other relevant rules, and appropriate bond release criteria noted in Subchapter 11 of ARM and in MSUMRA. Success or failure of channels and related work will be ultimately evaluated on a case-by-case basis in light of relevant rules and performance standards, and appropriate bond release criteria (e.g., ARM 17.24.1116).

APPENDIX A

Definitions Related to Drainage Reclamation

Bankfull Discharge The momentary peak flow; one which occurs several days in a year and is often related to the 1.5 year recurrence interval discharge (Rosgen, 1994).

Bankfull Stage The bankfull stage corresponds to the discharge at which channel maintenance is most effective, that is, the discharge at which moving sediment, forming or removing bars, forming or changing bends and meanders, and generally doing work that results in the average morphologic characteristics of channels (Dunne and Leopold, 1978; Rosgen, 1994).

Bankfull Width The water surface width measurement at the bankfull stage often corresponds with the normal high water discharge and is typically the discharge associated with the 1.5 year return period flow (Rosgen, 1996).

Channel The hollow bed where a stream of water runs or may run (Webster's Rev. Unabridged Dictionary, 1913).

A natural or artificial waterway that periodically or continuously contains moving water, or which forms a connecting link between two bodies of water (Univ. of Kentucky, 1985).

The bed and sides of a course; e.g., of a river (Kingston, 1988).

(a) The hollow bed where a natural body of surface water flows or may flow. The deepest or central part of the bed of a stream, containing the main current and occupied more or less continuously by water. (b) The bed of a single or braided watercourse that commonly is barren of vegetation and is formed of modern alluvium (colloquial: western U.S.A.). Channels may be enclosed by banks or splayed across and slightly mounded above a fan surface and include bars and mounds of cobbles and stones (Soil Survey Staff, NRCS, 1997).

Design The intentional shaping of matter, energy, and process to meet an expressed need (Federal Interagency Stream Restoration Working Group, 1998).

Divide Ridge beyond which water is drained by another system (Hamblin, 1995).

The summit area, or narrow tract of higher ground that constitutes the watershed boundary between two adjacent drainage basins; it divides the surface waters that flow naturally in one direction from those that flow in the opposite direction. Compare – interfluve (Soil Survey Staff, NRCS, 1997).

Drainage The manner by which the waters of an area flow off in surface streams or subsurface conduits; or, a collective term for all the water bodies by which a region is drained; a drainage system (Bates and Jackson, 1984).

Drainage Basin Land surface region drained by a length of stream channel (Pidwirny, 1999).

The entire area providing runoff to, and sustaining part or all of the streamflow of, the main stream and its tributaries (Gregory and Walling, 1973).

A region or area bounded by a divide and occupied by a drainage system; specifically,the tract of country that contributes water to a particular stream channel or system of channels, or to a lake, reservoir, or other body of water. Cf: river basin. Syn: watershed; hydrographic basin (Bates and Jackson, 1984).

A general term for a region or area bounded by a drainage divide and occupied by a drainage system (Soil Survey Staff, NRCS, 1997).

A region or area bounded by a drainage divide and occupied by a drainage system; specifically, the tract of country that gathers water originating as precipitation and contributes it to a particular stream channel or system of channels, or to a lake, reservoir, or other body of water (USFS).

An area largely enclosed by higher lands but having an outlet and being drained (Websters).

Drainage Density Ratio of the total length of all streams within a drainage basin to the area of that basin. It is a measure of the topographic texture of an area (Bates and Jackson, 1984).

The measure of the length of stream channel per unit area of drainage basin. Mathematically its is expressed as:

Drainage Density (Dd) = Stream Length / Basin Area (Pidwirny, 1999)

Drainage Divide The boundary between adjacent drainage basins; a divide (Bates and Jackson, 1984).

Topographic border between adjacent drainage basins or watersheds (Pidwirny, 1999).

Drainage Pattern The configuration or arrangement in plan view of the stream course in an area, e.g., dendritic drainage pattern. It is related to local geologic and geomorphic features and history. Syn: drainage network (Bates and Jackson, 1984; Soil Survey Staff, NRCS, 1997).

Ephemeral Stream A stream which flows only in direct response to precipitation in the immediate watershed or in response to the melting of a cover of snow or ice, and which has a channel bottom that is always above the local water table [ARM 17.24.301(36)].

Generally a small stream or upper reach of a stream, that flows only in direct response to precipitation. It receives no protracted water supply from melting snow or other source, and its channel is, at all times, above the water table. Compare - arroyo, intermittent stream, perennial stream; Soil Survey Staff, NRCS, 1997).

Erosion The wearing away of the land surface by running water, waves, or moving ice and wind, or by such processes as mass wasting and corrosion (solution and other chemical processes). The term "geologic erosion" refers to natural erosion processes occurring over long (geologic) time spans. "Accelerated erosion" generically refers to erosion in excess of what is presumed or estimated to be naturally occurring levels, and which is a direct result of human activities (e.g., cultivation and logging; Soil Survey Staff, NRCS, 1997).

Floodplain A level area near a river channel, constructed by the river in the present climate and overflowed during moderate flow events (Leopold, 1994).

The flat area adjoining a river channel constructed by the river in the present climate and overflowed at times of high discharge. The floodplain under construction is flooded frequently and at a relatively consistent recurrence interval of 1.5 years in the annual flood series, or 2 years out of 3 on the average. The valley level corresponding to the bankfull stage (Dunne and Leopold, 1978).

The nearly level plain that borders a stream and is subject to inundation under flood-stage conditions unless protected artificially. It is usually a constructional landform built of sediment deposited during overflow and lateral migration of the streams (Soil Survey Staff, NRCS, 1997).

That portion of a river valley, adjacent to the river channel, which is built of sediments during the present regimen of the stream and which is covered with water when the river overflows its banks at flood stage (Dictionary of Geologic Terms, 1976).

Relatively flat area found alongside the stream channel that is prone to flooding and receives alluvium deposits from these inundation events (Pidwirny, 1999).

A flat or nearly flat surface that may be submerged by flood waters (Websters).

The area a river covers with water when it spreads out during a flood (American Rivers, 1997).

Intermittent Stream A stream, or reach of a stream, that does not flow year-round (commonly dry for 3 or more months out of 12) and whose channel is generally below the local water table; it flows only when a) it receives baseflow solely during wet periods, or b) it receives ground-water discharge or protracted contributions from melting snow or other erratic surface and shallow subsurface sources. Compare - ephemeral stream (Soil Survey Staff, NRCS, 1997).

Long Profile The surface shape of a landform when measured in its longest direction. It often refers to a river, when it is obtained by noting the height of the water surface at increasing distances from the starting point (Kingston, 1988).

For a stream, a plot of the elevation of points on the water surface against distances along it. The vertical scale must always be greatly exaggerated, for almost all streams are hundreds of times longer than their vertical falls (Gilluly et. al., 1975).

Meander Sinuous shaped stream channel. Usually found in streams flowing over a very shallow elevation grade (Pidwirny, 1999).

The predominant channel pattern, as seen from above. Meandering channels can be highly convoluted or merely sinuous but maintain a single thread in curves having definite geometric shape (Leopold, 1994)

One of a series of sinuous curves, bends, or loops produced in the flood plain or a mature stream (Univ. of Kentucky, 1985).

One of a series of regular freely developing sinuous curves, bends, loops, turns, or windings in the course of a stream (Soil Survey Staff, NRCS, 1997).

A winding, crooked, or involved course (Webster's Rev. Unabridged Dictionary, 1913).

Meander Wavelength The full wavelength distance between two successive outside or inside channel bends (repetitive, crest to crest distance). The wavelength averages about 11 times the channel width and nearly always is between 10 and 14 channel widths (Leopold, 1994).

Point Bar Stream bar deposit that is normally located on the inside of a channel bend (Pidwirny, 1999).

The deposit formed around and against the convex bank in a channel bend. The top level of the point bar is generally flat and at the height of the floodplain. Sediment moving near the bed concentrates near the convex bank and tends then to be deposited, gradually extending the convex bank streamward in the growth of the point bar. The continual streamward extension of the point bar as the channel migrates laterally is a major process of floodplain formation. (Dunne and Leopold, 1978).

The depositional bar that characteristically occurs alternately on one side and then the other side of the channel. The distance between successive bars averages five to seven channel widths (Dunne and Leopold, 1978).

Crescent-shaped accumulation of sand and gravel deposited on the inside of a meander bend (Hamblin, 1995).

One of a series of low, arcuate ridges of sand and gravel developed on the inside of a growing meander by the slow addition of individual accretions accompanying migration of the channel toward the outer bank. Compare - meander scroll channel (Soil Survey Staff, NRCS, 1997).

Alternating wedge-shaped bars installed in the channel thalweg to guide low flows along the desired sinuous course. Bars are constructed at a height which does not interfere with flooding (McIntosh, 1989).

Reach An expanse of a stream channel (Pidwirny, 1999).

Stability As a characteristic of ecosystems, combines the concepts of resistance, resilience, and recovery. Resistance is the ability to maintain original form and functions. Resilience is the rate at which a system returns to a stable condition after a disturbance. Recovery is the degree to which a system returns to its original condition after disturbance (Federal Interagency Stream Restoration Working Group, 1998).

Stream A long narrow channel of water that flows as a function of gravity and elevation across the Earth's surface. Many streams empty into lakes, seas or oceans (Pidwirny, 1999).

Any body of running water that moves under gravity to progressively lower levels, in a relatively narrow but clearly defined channel on the ground surface, in a subterranean cavern, or beneath or in a glacier. It is a mixture of water and dissolved, suspended, or entrained matter. Also, a term used in quantitative geomorphology interchangeably with channel. Compare - river. stream channel - (not preferred) refer to channel (Soil Survey Staff, NRCS, 1997).

Stream Order The relative position, or rank, of a stream channel segment in a drainage network (Pidwirny, 1999).

An integer system applied to tributaries (stream segments) that documents their relative position within a drainage basin network as determined by the pattern of its confluence's. The order of the drainage basin is determined by the highest integer. Several systems exist. In the Straggler system, the smallest unbranched tributaries are designated order 1; the confluence of two first-order streams produces a stream segment of order 2; the junction of two second-order streams produces a stream segment of order 3, etc. (Soil Survey Staff, NRCS, 1997).

Swale A slight, open depression which lacks a defined channel that can funnel overland or subsurface flow into a drainageway. Soils in swales tend to be more moist and thicker (cummulic) compared to surrounding soils (Soil Survey Staff, NRCS, 1997).

In cross-section, a generally broad, shallow feature where runoff may become concentrated. A thalweg and a floodplain are generally not discernable (Rill & Gully guideline).

A slight depression, sometimes swampy, in the midst of generally level land (Bates and Jackson, 1984).

Upland Ground elevated above the lowlands along rivers or between hills (Merriam-Webster, 1991).

An informal, general term for (a) the higher ground of a region, in contrast with a low-lying, adjacent land such as a
valley or plain. (b) Land at a higher elevation than the flood plain or low stream terrace; land above the footslope zone of the hillslope continuum. Compare - lowland (Soil Survey Staff, NRCS, 1997).

Wavelength Distance between two successive wave crests or troughs (Pidwirny, 1999).

Width/Depth Ratio The ratio of bankfull channel width to bankfull mean depth (Rosgen, 1994).

Appendix B

TABLE 1

Meander width ratio (belt width/bankfull channel width) by stream type categories (modified from Rosgen, 1994).

Stream Type	Normal Slope Range*	Average Values	Range
A	4 - 10 %	1.5	1 - 3
D	<2 %	1.1	1 - 2
B & G	2 - 4 %	3.7	2 - 8
F	< 2 %	5.3	2 - 10
C	< 2 %	11.4	4 - 20
E	< 2 %	24.2	20 - 40

Note: Where no relevant pre-mine cross section data are available, the appropriate meander width ratio (Wblt / Wbkf) can give an approximate estimate of floodplain width (assumed similar to beltwidth) relative to bankfull width. Where possible estimates of meander width ratio should be calibrated to local conditions. Note for example, that the averages and ranges listed for F, C, and E channel types include data from very low gradient channel slopes (e.g., << 1%; see channel slope frequency histograms by stream type (Rosgen, 1996). In general , very low gradient channels would tend to have higher meander width ratios (relatively wider floodplains) than most low gradient reclaimed channels in Montana (e.g., relatively small drainages with 1-2% channel slope). Details of the dataset for C5 channel types, which include twice as many channels in the flatter slope subgroup (.002-.007 ft/ft) than in the steeper subgroup (.007-.0138 ft/ft slope); see C5 channel slope histogram (p. 5-102; Rosgen, 1996).

Appendix B

TABLE 2

Generic Channel Design Parameters Based on Bankfull Flow*

Bankfull Flow (cfs). These values would be based on 1.5 -2.0 yr. Recurrence interval)	Bottom Width of Channel (ft.)	Depth of Channel (ft.)	Meander Wavelength (ft.)	Expected Width of Flood-plain (ft.)
0.6 – 2	3	0.5	85 - 120	15
2.1 – 4	4	1.0	110 - 155	20
4.1 – 15	5	1.0	140 - 195	25
15.1 – 38	6	1.5	165 - 230	30
38.1 – 76	7	1.5	195 - 270	30
76.1 – 88	7.5	1.5	205 - 290	35

Values are for channels with slopes ranging from 2 to 5% and 4H:1V sideslopes*.**

Due to operational and construction considerations the values in Table I should be considered as target values, not exact dimensions that must be achieved. The range of deviation from these values will be dependent on site considerations. However, in general, deviations should not exceed values listed in adjacent rows, except for cutbanks, whose height may be considerably higher than the listed value for depth of channel. Due to compaction, the height of installed meander points (point bars) should be about six inches beyond the listed value for depth of channel. Values for CFS can be determined through computer modeling, potentially the Omang (1992) regression equations, or other acceptable means.

The Omang regression equation for the two year recurrence interval for Southeast Plains Region Montana is:

$Q^2 = 537\ A^{0.55}\ (E/1000)^{-2.91}$

Q is in cfs
A is contributing drainage area in square miles
E is mean basin elevation, in feet above sea level

Appendix B

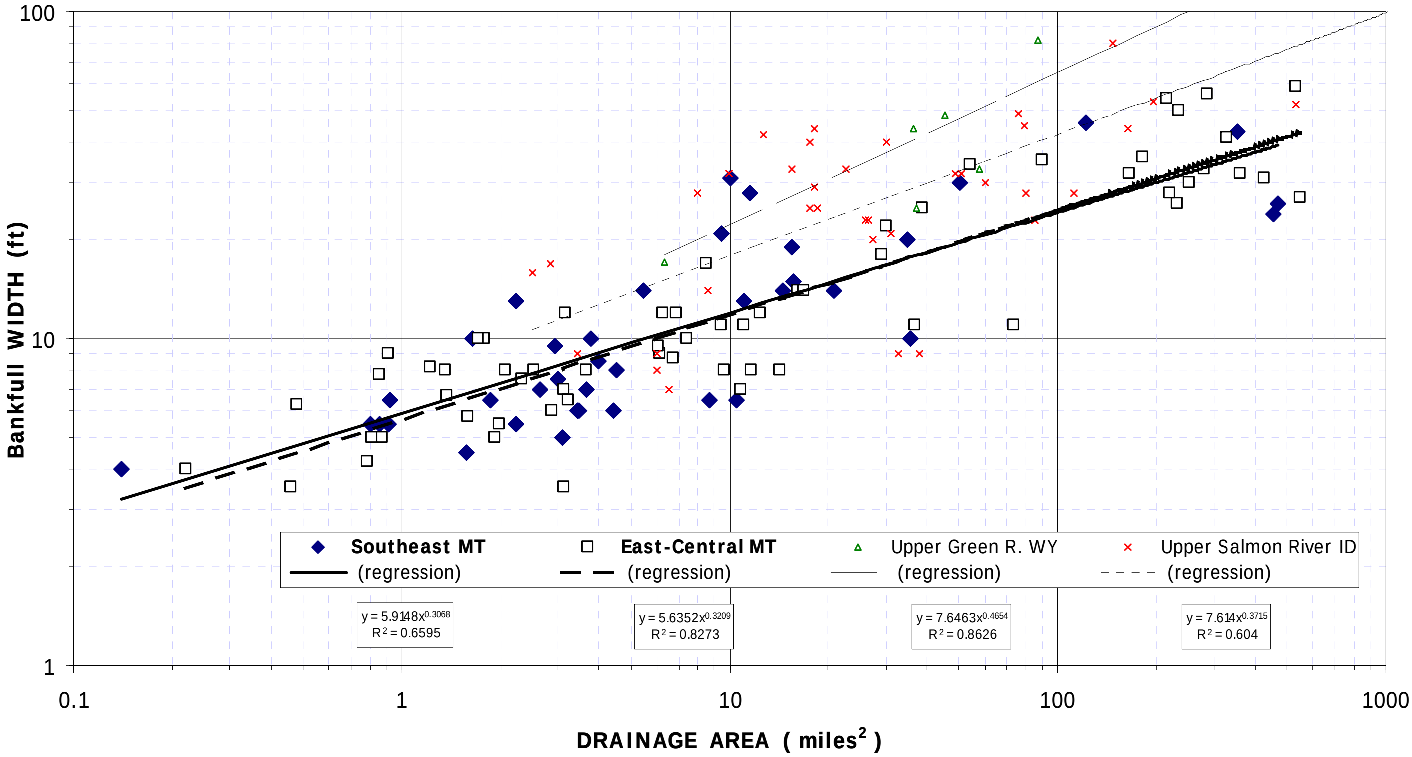

Figure 1. Bankfull Channel Width vs. Drainage Area for Southeast & East-Central Montana USGS sites; regional data (Wyoming and Idaho) are provided for comparison. Montana data from Parrett et al. (1987) and Omang (1992) with updates from Parrett (pers. com. , 5/2001); Upper Green River, WY and Upper Salmon River, ID data from Dunne & Leopold (1978); and Emmett (1975).

Appendix B (cont.)

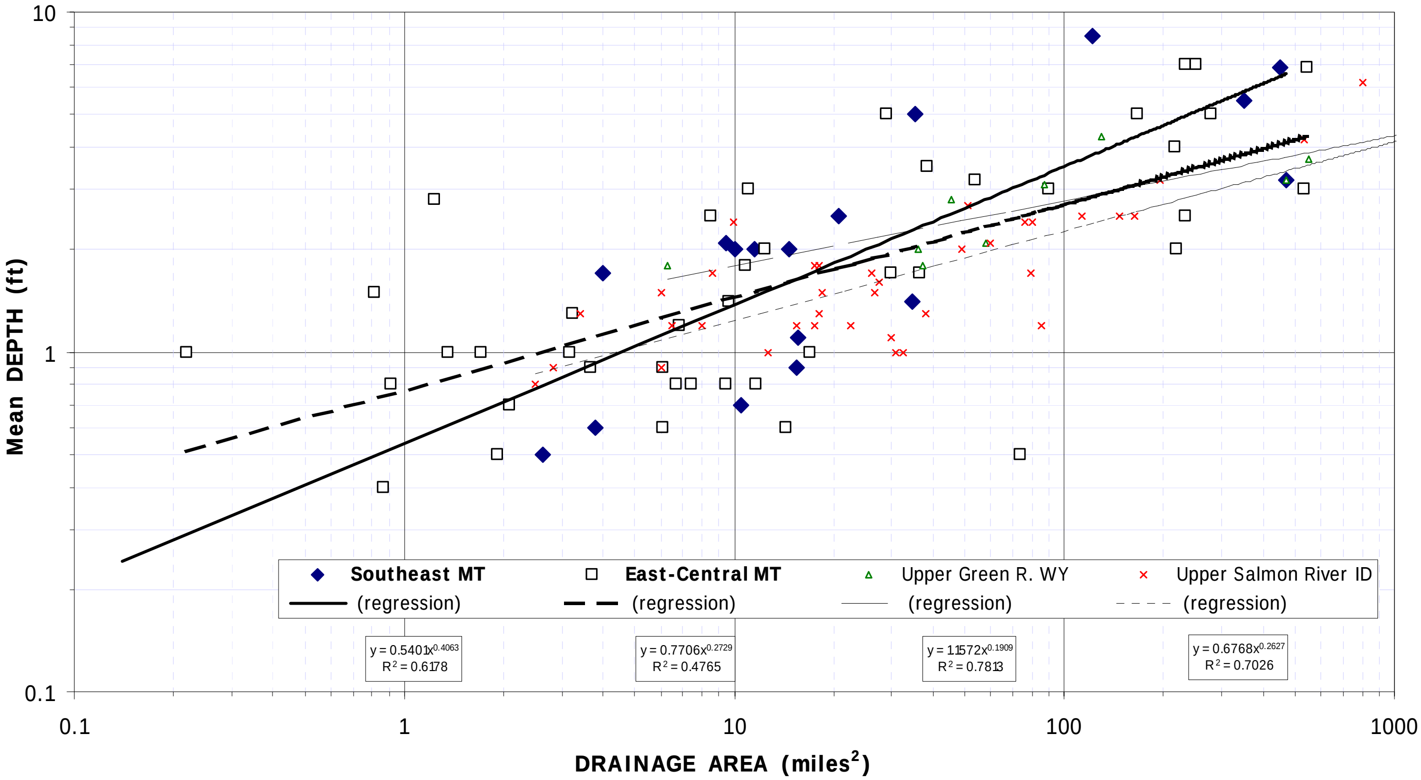

Figure 2. Bankfull Channel Depth vs. Drainage Area for Southeast & East-Central Montana USGS sites; regional data (Wyoming and Idaho) are provided for comparison. Montana data from Parrett et al. (1987) and Omang (1992) with updates from Parrett (pers. com. , 5/2001); Upper Green River, WY and Upper Salmon River, ID data from Dunne & Leopold, 1978; and Emmett, 1975.

Appendix B (cont.)

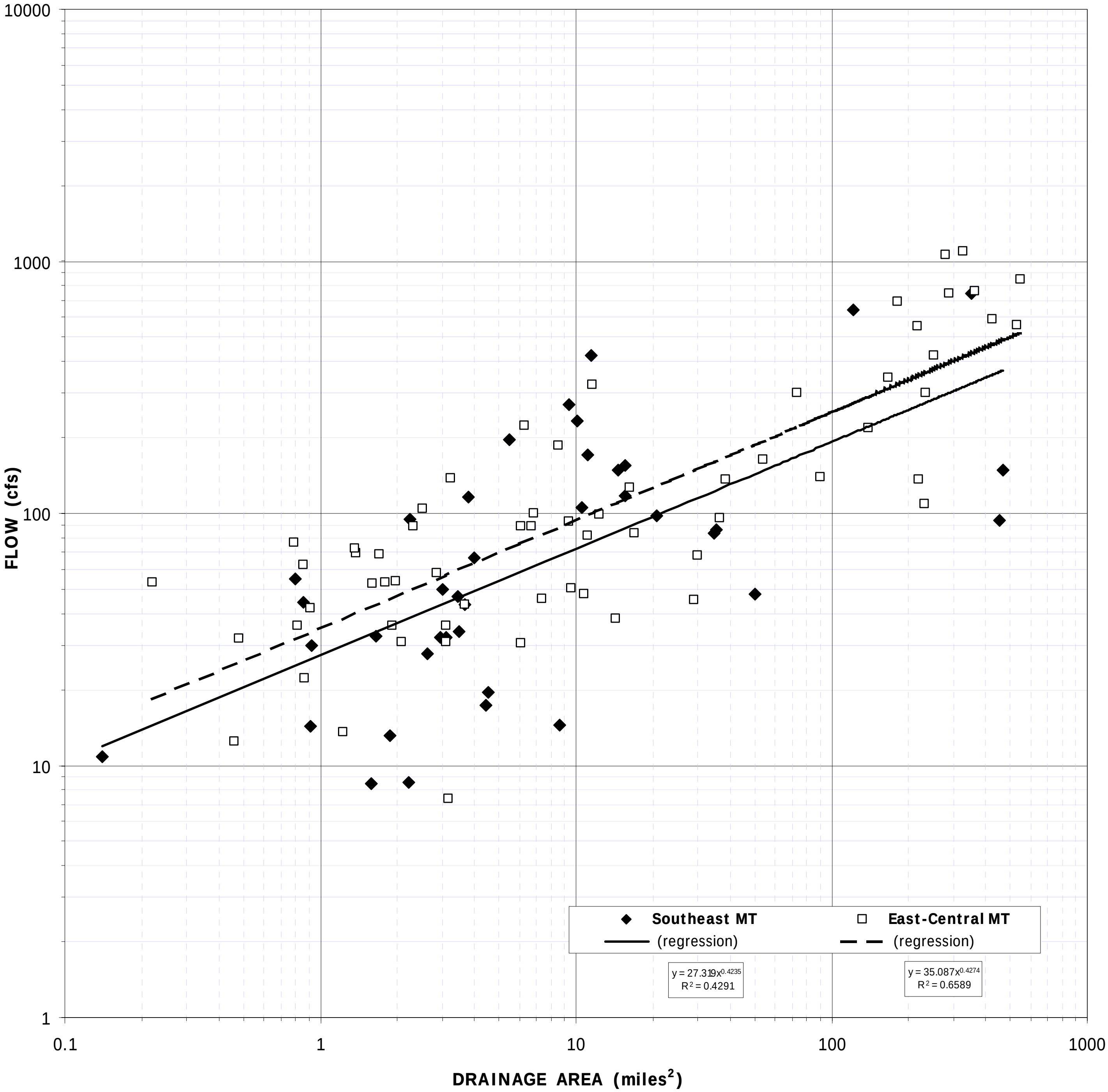

Figure 3. Two-year recurrence Peakflows vs. Drainage Area for Southeast & East-Central Montana USGS sites; data from Parrett et al. (1987) and Omang (1992) with updates from Parrett (pers. com. , 5/2001).

Appendix C

Text References

Dunne, T. and L.B. Leopold. 1978. Water in Environmental Planning. W.H. Freeman and Company, San Francisco. 818 pp.

Emmett, W.W. 1975. The Channels and Waters of the Upper Salmon River Area, Idaho. U.S. Geological Survey Professional Paper 870-A.

Leopold, L.B. 1994. A View of the River. Harvard University Press. Cambridge, MA. 298 pp.

Omang, R.J. 1992. Analysis of the Magnitude and Frequency of Floods and the Peak-Flow Gaging Network in Montana. U.S. Geological Survey Water-Resources Investigations Report 92-4048, 70 pp.

Parrett, C., J.A. Hull, and R.J. Omang. 1987. Revised Techniques for Estimating Peak Discharges from Channel Width in Montana. U.S. Geological Survey Water-Resources Investigations Report 87-4121, 34 pp.

Rosgen, D.L. 1996. Applied River Morphology. Wildland Hydrology, Pagosa Springs, CO.

Rosgen, D.L. 1994. A classification of natural rivers. Catena 22: 169-199.

References for Definitions

American Rivers. 1997. Glossary of River-Related Terms. Washington, D.C. [see http://www.amrivers.org/glossary.html

Barnhart, R.K. 1986. The American Heritage Dictionary of Science. Houghton Mifflin Company, Boston, MA.

Bates, R.L. and J.A. Jackson (eds.). 1984. Dictionary of Geological Terms, 3rd Ed. American Geological Institute, Anchor Books - Doubleday. New York. 571 pp.

California State Department of Transportation. 1997. Definitions of Drainage Terms. (Topic 806 in Highway Design Manual (online version:). Sacremento, CA http://www.dot.ca.gov/hq/oppd/hdm/chapters/t806.htm#i806-1

Dunne, T. and L.B. Leopold. 1978. Water in Environmental Planning. W.H. Freeman and Co., San Francisco. 818 pp.

Federal Interagency Stream Restoration Working Group. 1998. Stream Corridor Restoration: Principles, Processes, and Practices http://www.usda.gov/stream_restoration

Gilluly, J., A.C. Waters, and A.O. Woodford. 1975. Principles of Geology, 4th Ed. W.H. Freeman and Co., San Francisco. 527 pp.

Gregory, K.J. and D.E. Walling. 1973. Drainage Basin Form and Process. Halstead Press, John Wiley & Sons, New York. 458 pp.
Hamblin, W.K. 1995. Earth's Dynamic Systems. Ch. 12. River Systems: http://riverresource.com/text/river%5Fsystems.html

Kingston, J. 1988. Longman Illustrated Dictionary of Geography. Longman -York Press, Essex, UK. 256 pp.

Leopold, L.B. 1994. A View of the River. Harvard University Press. Cambridge, MA. 298 pp.

Merriam-Webster. 1991. Webster's Ninth New Collegiate Dictionary. Merriam-Webster, Inc., Springfield, MA.

Nevada Division of Water Planning. 1997. Water Words Dictionary (online version). Department of Conservation and Natural Resources, City, NV http://www.state.nv.us/cnr/ndwp/dict-1/waterwds.htm

Pidwirny, M. 1996-99. Online Glossary of Terms for Physical Geography. Dept. of Geography, Okanagan Univ. College, Kelowna, British Columbia. http://www.arts.ouc.bc.ca/geog/physgeoglos/glossary.html

Rosgen, D.L. 1994. A classification of natural rivers. Catena 22: 169-199.

Soil Survey Staff, Natural Resources Conservation Service. 1997. Glossary of Landform and Geologic Terms. (Part 629) in: National Soil Survey Handbook, title 430-VI. Washington, D.C., U.S. Government Printing Office, December 1997. http://www.statlab.iastate.edu/soils/nssh/629.htm#y